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INFLUENCE OF THE CENTRAL ASIATIC MOUNTAINS ON THE FORMATION OF THE JET STREAM

[Following is a translation of an article by P. Pogosyan and K. F. Ugarova in Meteorologiya i Gidrologiya (Meteorology and Hydrology), No. 11, Moscow, 1959, pages 16-26.]

Many studies have been devoted to the investigation of the influence of mountain ranges, most of all of the Central Asiatic Mountain Range, on the formation and the variation of intensity and on the seasonal position of tropospheric jet streams. The majority of investigators believe that the Himalayas and Tibet exert a substantial influence on atmospheric circulation at high altitudes and therefore also on jet streams.

It is hard to disagree with the conclusions of Tu Cheng Yeh /4,16/ and other Chinese authors /17,18/ about the influence of the above-mentioned mountain range on atmospheric circulation in the lower half of the troposhpere and on the weather of China and Northern India.

It is also pointed out that Tibet and the Himalayas exert influence mainly during the cold part of the year and that they have very little influence during the warm part of the year. The latter case is caused by the fact that towards summer the altitudinal frontal zone and the jet stream are displaced northward, beyond the limits of this upland.

During the cold half of the year, according to these notions, the western aerial current (jet stream) branches out on meeting the mountain range. As a result of the mechanical action of the mountains, two jet streams appear north and south of the highlands. The northern branch of the stream possesses greater mobility than does the southern because, according to the opinion of the abovementioned authors, the displacement of the southern branch is limited by the Himalayas.

Soviet meteorologists also attach substantial importance to the influence of the mountains on the character of atmospheric circulation in Central Asia, indicating that large horizontal gradients of pressure and of wind velocity at the 5-6 km level south and north of Tibet are due to the presence of the mountain range /2, 6, 13/.

Aerological observations performed over Tibet in the course of last two years permit a comparatively more pene-

trating investigation of seasonal variations of the fields of temperature and wind, as well as of altitudinal frontal zones and jet streams. During 1957-59, we constructed several series of individual and mean cross-sections of the atmosphere between the Equator and North Pole along different meridians and in different seasons above Eurasia and North Africa.

Some monthly profiles express not only subtropical but also extratropical jet streams. It appeared that, regardless of orography, during the winter months, the subtropical jet streams in the Northern Hemisphere can be found mostly in the 26-30° N latitudinal zone. This corresponds with their recurrence in winter, determined by the velocity of the wind at the 300 mb /7/ level. Only during certain periods of time, with significant meridianal transformations of the altitudinal thermobaric field, and the development of a high cold cyclone due to isolation (blocking), at the 30-40° latitudes, the axis of the sub-tropical stream can be located at 20-25° N latitudes.

During the summer, under the influence of the circulation of the atmosphere of extratropical latitudes, a change of location and intensity of the subtropical jet stream is observed /8/.

We shall cite here only two mean monthly profiles (January and July) over Tibet and Eastern Siberia (Figs. 1 and 2), and, as a supplement, data on the geographical position and intensity of jet streams during winter and summer over different longitudes.

These data are given in Table 1 for four longitudes: Western Africa - Greenland, Arabia - North Pole (over the European part of the USSR), India - North Pole (Over the Japanese islands). Here are represented data on the latitude of the location of the axis of extratropical and subtropical currents at given longitudes in different seasons. It is easy to determine by comparison that in January the subtropical jet streams everywhere fall at a comparatively narrow latitudinal range, when, however, the physical-geographical conditions in the subtropical zone of the Northern Hemisphere are far from being homogeneous.

At the same time, depending on the character of the prevalent circulation form, extratropical streams can be found over most different latitudes ranging from the subtropics to 80° N; that is, in a range of more than 4-5,000 km /11,12/.

As investigations have demonstrated, intraseasonal displacements, as well as the average monthly position, of the axis of the subtropical jet stream are also determined by the character of the circulation in the hemisphere.

Thus, for instance, the anomalous southern position of the axis of the subtropical stream over Western Africa in 1959 was stipulated by significant meridional transformations of the thermobaric field of the troposphere, accompanied by frequent invasions of cold to the south, and by the development between the Azores and Western Africa of an isolated (blocked) high cold cyclone, at the southern periphery of which the strengthening of the subtropical stream took place. A similar anomaly, however, is comparatively rare. It is not accidental that, with the exception of Western Africa, during 1958-59, the axes of all other subtropical streams were located between 27 and 33° N.

These facts lead to the conclusion that the position of subtropical jet stream over India and Tibet is not stipulated by the presence of the Central Asiatic mountain range, but by general conditions, specific as well for other subtropical regions.

From the constructed vertical cross-section of the atmosphere along the line Trivandrum - NP-7, passing over India, Tibet and Siberia, it can be seen that the subtropical jet stream is located not only in the Himalayan foothills but also over the mountain ranges (Fig. 1). That is, the displacement of the axis of the subtropical stream is not limited by the foothills. In individual cases, as, for instance, on 6-10 February 1958, with the displacement of the warmth crest northwards, the axis of the subtropical jet stream was located immediately over the mountain range at the 29-30N latitude. As far as the maximal wind velocities at the jet axis are concerned, their magnitude is substantially dependent upon the prevalent synoptic processes.

Physical-geographical conditions exert an influence on the intensity of the subtropical stream in different seasons. In particular, high wind velocities over the Japanese islands are due to large contrasts of temperature which occur between the condensed air over Asia and the warm air over the ocean /11/. During a west-east transfer, meridianal processes occur here almost incessantly, accompanied by advection of cold, causing cold air from Siberia and Mongolia and warm air from the Pacific Ocean to draw together. This process is so predominant that it is reflected even on median AT_{500} and OT_{1000}^{500} maps, on which a depression of cold and low pressure is clearly expressed over Yakutia and the Far East during winter /11/.

At the same time, over Arabia and India, where physical-geographical conditions and the character of circulation do not cause the formation of such significant temperature contrasts, jet streams are comparatively weaker.

As has been stated earlier, the position of extratropical jet streams is less stable because their formation is directly related to cyclonic activity. During some years therefore, depending upon the prevalent processes, the greatest frequency of jet streams can be observed over various latitudes. At the same time, due to physical-geographical peculiarities, the greatest frequency of extratropical jet streams is observed at the 10° W meridian, predominantly within the limits of 50-60°N latitudes.

This zone of maximal frequency of extratropical jet streams is also detected over the European part of the USSR and Western Siberia, while, however, the intensity of streams decreases with eastward displacement. Further to the east, extratropical jet streams are most often observed somewhat more to the south, in the 40-50°N latitudinal zone (Mongolia, Northern China), and over Japan they usually merge with the subtropical jet.

It follows from the above that the extratropical jet stream observed over Mongolia and Northern China is not in any way connected with the Central Asiatic mountain system. Concurrently, as data of aerological observations shows, extratropical jets develop sporadically also in the foothills of Tien-Shan and Tibet. Their formation, however, is not connected with the branching of the subtropical stream, but with a meridional transformation of a thermobaric stream, accompanied by an invasion of cold masses of air into Kazakhstan and Central Asia. An analysis of one of the examples of the formation of a similar jet stream will be given below.

Thus, the conclusion can be made that jet streams, found to the north and to the south of a mountain range, develop independently of one another and are not branches of the same stream.

The position of the jet streams changes substantially toward the summer. Subtropical jet streams over the entire Northern Hemisphere are displaced on the average 1400-1600 km northward. Concurrently, in connection with the total decrease of temperature contrasts between theEquator and the Pole, jet streams decrease markedly. Instead of 180-220 km/h in wintertime, maximal velocities in summer do not exceed 100-140 km/h on the average. The greatest weakening of jet streams from winter to summer is observed over the Japanese islands; it is due to a warming up of the Asiatic mainland and to a substantial decrease of temperature contrasts between the continent and the ocean.

Changes in the position and intensity of jet streams, which have occurred from winter to summer, can be seen on the example of a region of India, Tibet and Siberia, the mean

vertical profile of the atmosphere for July 1958 ~~of~~ which is represented in Fig. 2.

As the data in Fig. 2 shows, the position of the subtropical jet stream in summer is approximately the same at all studied longitudes in the 42-44°N latitudinal zone. Consequently, the mountain range of Central and Middle Asia does not exert any significant influence on the seasonal position of jet streams.

However, this cannot be said in relation to the intensity of jet streams. Thus, in July 1958, the mean velocity of the jet stream north of Tibet appeared to be somewhat greater than in other regions. This fact might be explained by the radiational conditions of the high plateau /1,3/. Yet, the fact has to be taken into consideration that, due to geographical conditions over the southern Asiatic mainland, warming up of the air progresses most intensively. In the conditions of Central Asia, the comparatively cold masses of air progressing inland invading the continent from the north and the northwest, are warmed up continuously. This occurs not only over the mountain ranges of Central Asia but also to the west of them, in almost mountainless regions. At the time of the general west-east transfer, water vapor in the warming air is eliminated from the state of saturation, fronts are eroded. Even in the system of depressions, moving in from the west or developing in Central Asia, clear weather is observed, which facilitates the radiational warming up of the underlaying surface and air. It is easy to discover on the mean monthly maps of baric topography that, starting from the northwestern coastal areas of Africa and the Pyrenees and on to Central Asia, the structure contours OT^{500}_{1000} /12/ are gradually displaced northward; that is, the process of the warming up of air with the eastward movement is expressed on mean OT maps independently of the presence or absence of mountains. It is possible that warming up of air occurs somewhat more intensively over Tibet than over adjacent regions. It is evident, however, that irrespectively of the existence of the mountain range, the altitudinal crest could still be located over these regions as a result of the west-east transfer and the warming up of the air.

In spring and in autumn, the subtropical jet stream occupies a position which is intermediate between the winter (27°N in January) and the summer (43°N in July) positions. On the 90°E meridian as well as in other regions, the jet stream is displaced in the spring from south to north and in autumn from north to south. The disappearance of the stream in May over India /14, 15/ is explainable by the fact that

the planetary altitudinal frontal zone is displaced into more northern regions in accordance with the radiational conditions.

The gradual transfer of the subtropical stream during April, May and June is demonstrated in Fig. 3. A time profile of the direction and velocity of wind for five stations, located approximately along the 90° E meridian in the foothills and over the mountain range, is depicted here.

It follows from the data in Fig. 3 that strong winds are observed in April predominantly over the north of India; that is, the subtropical stream still almost maintains its winter position.

According to the mean cross-section for April along the 90°E meridian, the axis of the subtropical stream is located at the 29°N latitude. The position in May is already different. Strong winds are observed mainly over Lhassa and Kheermu; in Calcutta the strong winds completely disappear; that is, the subtropical jet is displaced northwards to the upland.

As an example, a vertical cross-section at 15 h., 14 May 1958, along the line Trivandrum - SP-7 9Fig. 4) can be cited. Here, according to the data of the actual wind, the axis of the jet is located approximately at 35°N latitude, i.e., directly over the mountain range. North and South of the Himalayas and Tibet the wind velocities decrease sharply. The transfer to the summer position occurs in June. Toward the middle of that month, the strong winds over Lhasa have already completely disappeared. A subtropical jet stream is located over the northern periphery of Tibet.

In autumn, a displacement of the subtropical jet from north to south occurs in a similar manner. It can be seen on the time cross-section for September, October, and November (Fig. 5.) that the maximal frequency of strong winds moves gradually from the northern regions to the southern. If in September winds with 100 km/h velocity can be observed only in Zhatsyan and Khermu, in October they are already noticed also in Lhasa. In the middle of October, as mentioned by several investigators /14, 15, 16/, a sudden appearance of a jet stream over the north of India takes place. Judging from a vertical cross-section of atmosphere along the 90°E meridian for October 1958, the axis of the subtropical jet can be observed on the average at 38°N latitude. Strong winds appear in November over Gaukhati and Calcutta. Strong winds in November are also often observed north of Tibet.

These are, however, already extratropical jet streams, the axis of which are located close to the 300 mb surface level, while maximal velocities at the axis of a subtropical are usually located close to the 200 mb surface level.

Thus, the sudden development of a subtropical jet stream over Northern India in October, as well as its disappearance in May, is related to seasonal displacements of a jet stream which here, as well as in other regions of the subtropical zone, is determined by general radiational conditions.

We would like to dwell longer on a single example of the evolution of a jet stream in a region of Central and Middle Asia in the period of 2-12 January 1959. Maps of equal velocity lines of the isobaric 300 mb surface, maps of diurnal variations of the temperature of the troposphere, and vertical cross-sections for that period were prepared.

According to the analyzed material, in the beginning of the period investigated, three jet streams were observed over the territory of Asia; two extratropical and one subtropical, which merged over the Far East, forming a wide zone of strong winds. The extratropical jet streams were branches of a jet which passed over the European territory of the USSR. One of the branches was located over the north of Western Siberia and later over Eastern Siberia in more southern latitudes. The second, more intensive, branch passed over the Caucasus, south of Middle Asia, and further along the northern frontier of the mountain range.

The equal-velocity maps demonstrate clearly that the presence of two jet streams north and south of the Himalayas and Tibet was not caused by a branching of the jet under the influence of the mountain range: a subtropical jet passed in the south and one of the branches of the extratropical jet did so in the north.

Invasions of cold in Middle Asiatic territory have periodically led to the strengthening of the extratropical jet stream on the northern periphery of the mountain ridges. Concurrently with a very strong advection, the subtropical jet grew stronger as, for instance from 2 January to 4 January, when the invasion of cold to the north of India here caused a significant increase of maximal velocities, from 140 to 250 km/h in the center of the jet and from 60-90 to 110-160 km/h at the 500 mb surface level. 24 hours later, after the air warmed up, the contrasts of temperature and the wind velocities correspondingly decreased over India.

During this period the southernmost branch of the extratropical jet stream has, as a result of displacement of the altitudinal trough and of the focus of cold to the east, also been displaced eastward; in the morning of 4 January it could not be detected any more over the Caucasus and toward 6 January strong winds disappeared completely over the territory of Middle Asia and Pamir. Two branches of the

extratropical jet stream still existed on 6-7 January in the more eastern regions. In the following days, the southern branch of the extratropical jet was displaced in accordance with synoptic processes into the region of Tibet and Southeastern China and toward 10 January it merged with the subtropical jet at the 25-30°N latitudes.

Besides the subtropical jet, during 10-14 January over Asia an extratropical jet stream was observed which passed markedly to the north of the upland. Only weak winds were detected over Middle Asia and the foothills of the Central Asiatic range. Only beginning with 15 January did a new extratropical jet begin to develop over the northern foothills of Tien-Shan as a result of synoptic processes.

Thus it also follows from the cited example that the Central Asiatic mountain range does not present an obstacle, dividing the jet stream into two parts - a northern and a southern one. The origins and development of extratropical and subtropical jet streams occur absolutely independently and are due mainly to the general seasonal radiational conditions and circulatory processes /7/.

The position of the subtropical jet during transitional seasons directly over the mountain range once more demonstrates convincingly that Tibet and the Himalayas are not obstacle that limit the passage of jet streams over them.

The process of merging of jet streams over the east of Asia originates under definite forms of meridional circulation and can take place in any other region of the subtropical zone. Due to physical-geographical conditions, however, the merging of extratropical and sub-tropical jet streams most frequently takes place over Eastern China and the Japanese islands.

As far as the influence of radiatinnal warming up and cooling of air over Tibet on the seasonal position and intensity of the subtropical jet stream is concerned, according to our view this problem is not of a decisive nature. As we have seen, independently of the presence or the absence of mountain ranges, formation and seasonal displacements of subtropical jet streams take place in all regions of the earth almost identically.

In conclusion, we consider it necessary to dwell on a report, published recently by a group of authors /5/, dealing with the influence of mountain systems on the formation of a jet stream.

It contains mean monthly vertical cross-sections, drawn over lowldnds (along the 64°E meridian) and over the mountain systems of Middle Asia (along the 73°E meridian)

for August 1956 and September 1957. On the basis of an analysis of the cross-section, the authors maintain that "an orographically-conditioned jet stream corresponds to each large mountain system: a maximum over Dzhambul - Arkit corresponds to the Tien-Shan mountain system, a maximum over Osh - Sary-Tash corresponds to the Pamir-Altai system."

Through a thorough study of investigation data, particularly ofthe daily maps of baric topography of upper levels, we have established that in August 1956 the axis of the jet stream was displaced several times, together with the cold invasions far to the south so far as a contrast of temperature existed, independently of the presence or absence of a mountain range. The same can be ascertained from the figures which accompany this report /5/. Over mountains as well as over lowland, there can be observed a wide zone, elongated southward, of great wind velocities,in which displacement of individual jet streams took place during the month, on both cross-sections for August 1956 (/5/, Figures 1 and 2).

Two closed equal-velocity lines of 20 and 25 m/sec are represented over the mountain systems (Fig. 2); at the 40-42° latitude a closed center with 19 m/sec velocity can be found; consequently, the presence of an independent maximum of the velocity of wind over the mountain crests is stipulated not so much by the mountain range as by general circulatory conditions, characteristic also for adjacent lowland areas.

We do not tend to deny completely the influence of large mountain systems on the character of wind in the troposphere. It is obvious that the encounter of cold aerial masses with mountainous obstacles of 4-5 km average height and the development of large temperature contrasts is accompanied by some acceleration of wind at altitudes, particularly on the surface of the axis of a jet stream. It is difficult to state at this time the order of magnitudes of this additional acceleration of wind velocity. More complete data are necessary for its determination. Yet, as was demonstrated above the formation and evolution of a jet stream is determined mainly by general radiational and circulatory conditions.

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Table 1

The Position and Intensity of Western Jet Streams in January 1957-59 at Different Longitudes

Year	Line of Cross-Section	Subtropical Jet			Extratropical Jet		
		Latitude of position of axis of the jet (in °'s)	Maximal velocity (km/h)	Altitude of axis of the jet (mb)	Latitude of position of axis of the jet (in °'s)	Maximal velocity (km/h)	Altitude of axis of the jet (mb)
1957	ARABIA - NORTH POLE	29	220	180	57	80	320
	WESTERN AFRICA - GREENLAND	27	200	160	49 - 59	110 - 120	300 - 250
	ARABIA - NORTH POLE	31	180	190	57	120	250
1958	WESTERN PACIFIC - NORTH POLE	33	220	200	—	—	—
	WESTERN AFRICA GREENLAND	21	180	200	61	120	260
	ARABIA NORTH POLE	31	180	200	57	100	300
1959	INDIA - NORTH POLE	27	190	200	52	90	250
	WESTERN PACIFIC - NORTH POLE	32	220	200	—	—	—

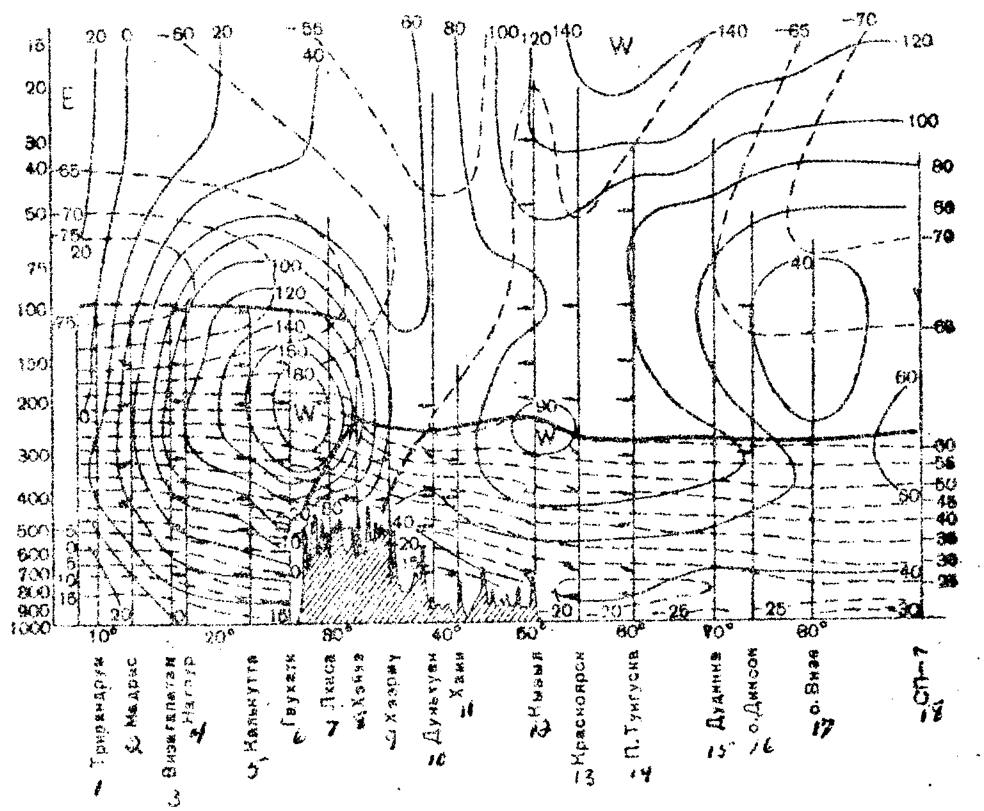

Fig. 1. Mean vertical cross-section of the atmosphere along the line Trivandrum - NP-7. January 1959.

1) Trivandrum. 2) Madras. 3) Vizagapatam. 4) Nagpur. 5) Calcutta. 6) Gaukhati. 7) Lhasa. 8) Heikhe. 9) Kheermu. 10) Tungkuang. 11) Khami. 12) Kyzyl. 13) Krasnoyarsk. 14) Tunguska. 15) Dudinka. 16) Dixon Island. 17) Vize Island. 18) NP-7.

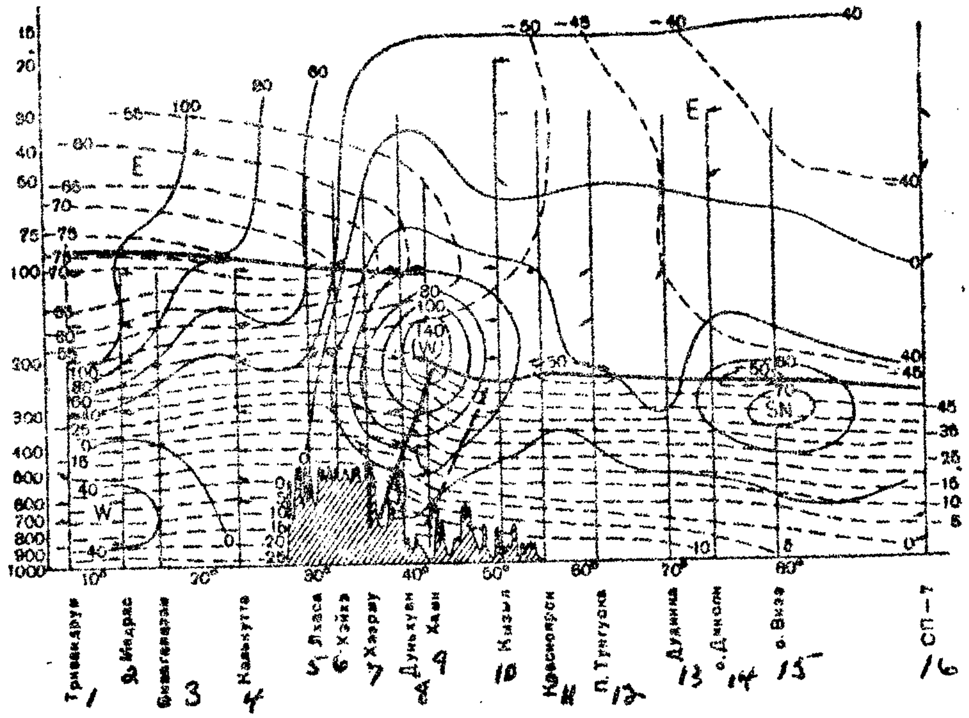

Fig. 2. Mean vertical cross-section Trivandrum - NP-7. July 1958.
1) Trivandrum. 2) Madras. 3) Vizagapatam. 4) Calcutta. 5) Lhasa. 6) Kheykhe. 7) Kheermu. 8) Dun'khuan. 9) Khami. 10) Kyzyl. 11) Krasnoyarsk. 12) P. Tunguska. 13) Dudinka. 14) Dixson Island. 15) Vize Island. 16) NP-7.

Table 2

The Position and Intensity of Western Jet Streams in July 1956-58 at Different Longitudes.

Year	Line of Cross-Section	Subtropical Jet			Extratropical Jet		
		Latitude of position of axis of the jet (in °s)	Maximal velocity (km/h)	Altitude of axis of the jet (mb)	Latitude of position of axis of the jet (in °s)	Maximal velocity (km/h)	Altitude of axis of the jet (mb)
1956	ARABIA NORTH POLE	43	140	200	67	80	320
1957	ARABIA NORTH POLE	44	100	201	77	80	310
1958	WESTERN AFRICA GREENLAND	43	100	200	54	90	240
	ARABIA NORTH POLE	42	120	200	64	90	280
	INDIA NORTH POLE	43	140	180	80	70	300
	WESTERN PACIFIC NORTH POLE	43	110	200	60	70	260

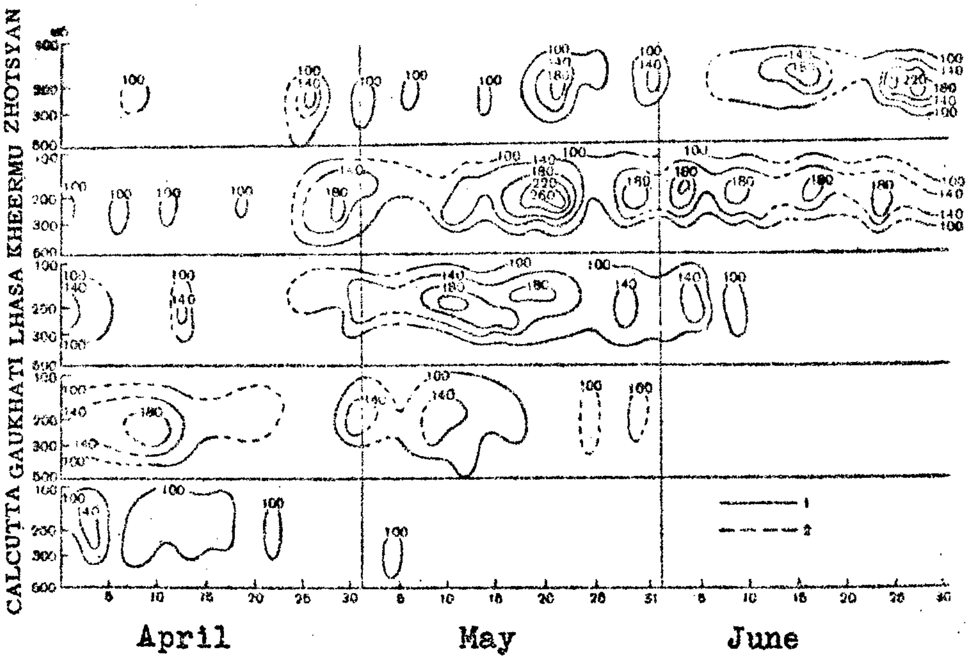

Fig. 3. The time vertical cross-section of wind for station

Zhotsyan (38°05' N latitude, 88°03' E longitude),
Kheermu (36°12' N latitude, 94°38' E longitude),
Lhasa (29°43' N latitude, 91°02' E longitude),
Gaukhati (26°05' N latitude, 91°43' E longitude),
Calcutta (22°39' N latitude, 88°27' E longitude),
for April - July 1958. 1 - equal-velocity lines of an observed western wind at ≥100 km/h velocity; 2 - equal - velocity lines of a geostrophic wind.

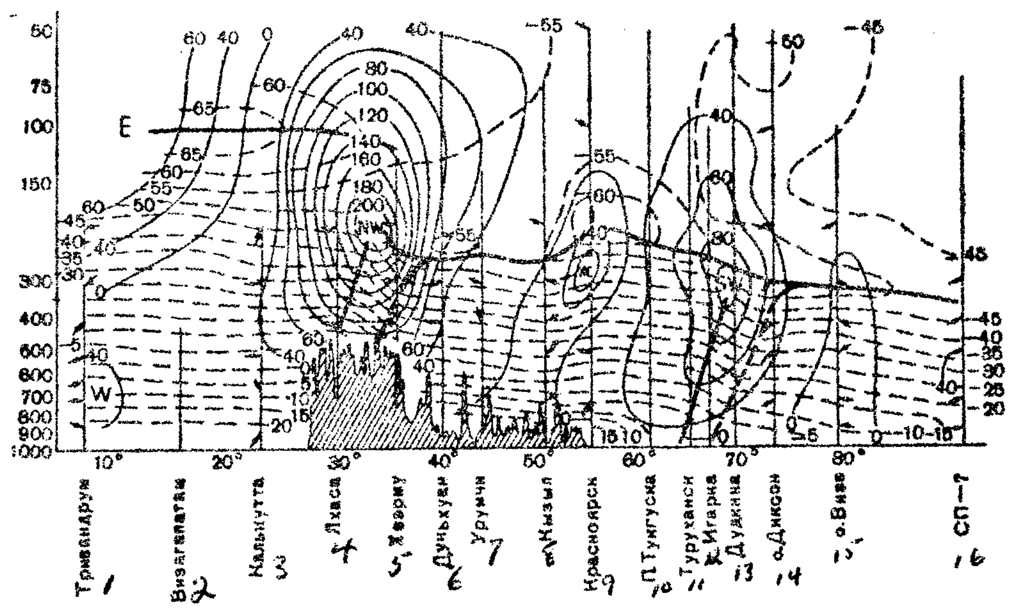

Fig. 4. Vertical cross-section of atmosphere along line Trivandrum - SP-7 at 15 h., May 14, 1958.

1) Trivandrum. 2) Vizagapatam. 3) Calcutta. 4) Lhasa. 5) Kheermu. 6) Tungkuang. 7) Urumchi. 8) Kyzyl. 9) Krasnoyarsk. 10) P. Tunguska. 11) Turukhansk. 12) Igarka. 13) Dudinka. 14) Dixon Island. 15) Vize Island. 16) NP-7

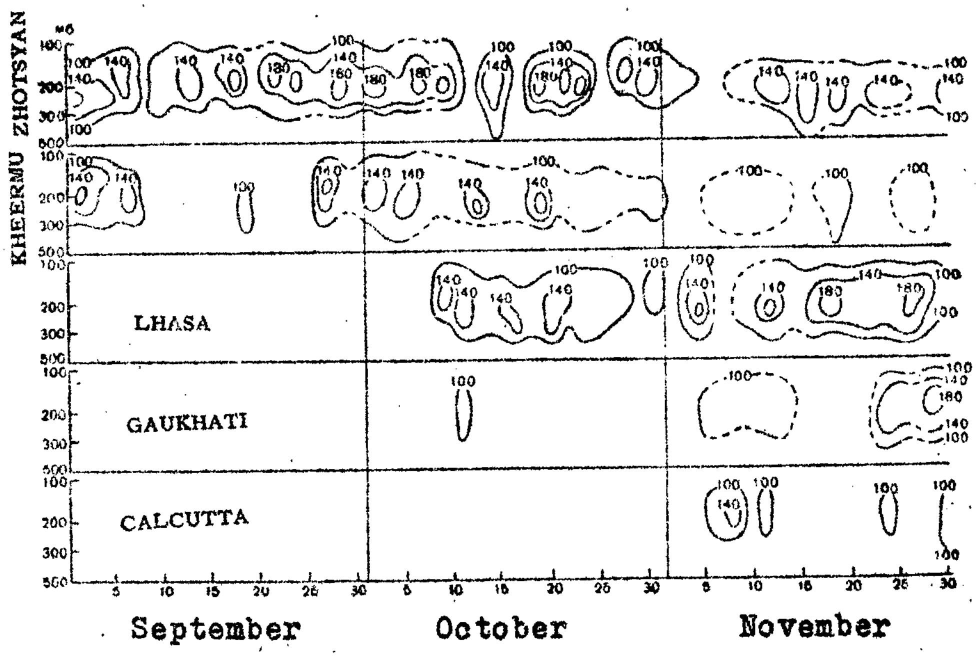

Fig. 5. Time vertical cross-section of wind for stations Zhotsyan. Kheermu. Lhasa, Gaukhati, Calcutta for September-November 1958.

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